Joule Heating in Electroosmotically Driven Circular Constriction Microchannel

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Abstract

Introduction

The major applications of microfluidics are in lab-on-a-chip (LOC) devices. Liquid transport in LOC devices occurs through the microchannel which uses an electroosmotic flow actuation mechanism. This is the preferred method due to its plug-like velocity profile which is ideal in species transport and in wall-bounded reactions. Electroosmotic flow has a major disadvantage called joule heating. Under substantial joule heating, it is not possible to maintain a plug-like velocity distribution and this adversely affects the species transport.

My work investigates the effects of joule heating in a circular constriction microchannel where a layer of polydimethyl siloxane (PDMS) is also included along the liquid domain (figure 1) so that the temperature rise in the moving liquid due to joule heating also increases the temperature of the solid PDMS wall by conduction, which makes this a conjugate heat transfer problem. Different values of zeta potential are used for the simulation.

Use of COMSOL Multiphysics®

Simulations are done using COMSOL Multiphysics®. A 2D axisymetric model is used for simulation. Electric potential (DC) is applied across the channel for the occurrence of electroosmotic flow. Three equations are used in this problem: electric current balance equation, Navier-Stokes along with continuity equation for the flow field and a conduction-convection equation which accounts for the heat transfer. The electric currents section in the COMSOL AC/DC Module and the conjugate heat transfer section in the Heat Transfer Module are used for the simulations.

Results

Results are obtained by varying the value of zeta potential. The constriction channel geometry is also varied by giving a taper, keeping the inlet diameter and length of the constriction channels the same. Low values of zeta potential causes a larger temperature rise compared to a high value of zeta potential. For low values of zeta potential the temperature rise is observed only along the constriction channel, shown in Figure 2. When the value of the zeta potential is increased, then the temperature rise spreads towards the outlet, shown in Figure 3. Tapering the channel causes a considerable temperature rise due to joule heating towards the tip of the taper, shown in Figure 4.

Conclusions

Joule heating occurring in an electroosmotic flow in a circular constriction microchannel is simulated and results are obtained by varying the electric potential, zeta potential and also by providing a taper to the constriction channel. A low zeta potential causes a much larger temperature rise, but the temperature rise is confined to a small area; at high values of zeta potential the temperature rise is small compared to the low zeta potential case, but the temperature rise occurs in a much larger area. Tapering causes the temperature rise to concentrate more a the end of the taper, and the temperature rise is not uniform throughout the channel. Joule heating is a inevitable phenomenon occurring in all LOC devices but one can control the temperature rise by carefully selecting the values of zeta potential and electric potential.

Reference

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Figures used in the abstract

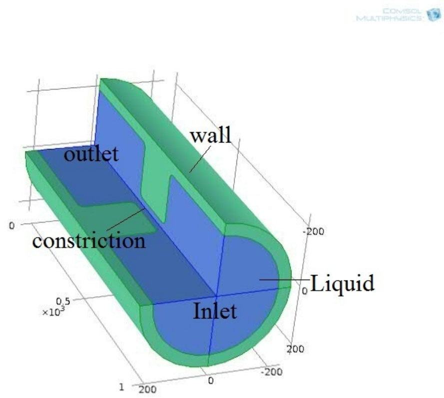

Figure 1: Geometry used for the problem

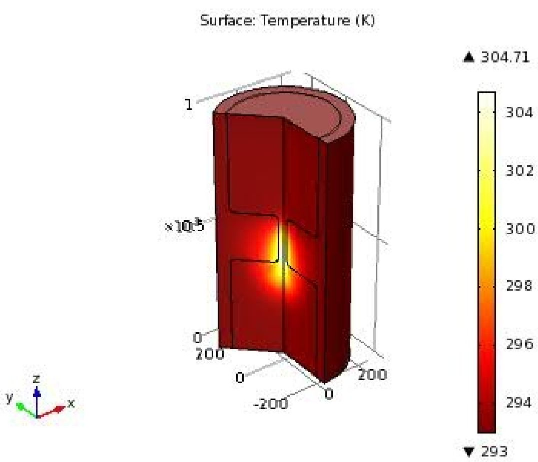

Figure 2: Figure showing the temperature rise along the constriction channel for low zeta potential value

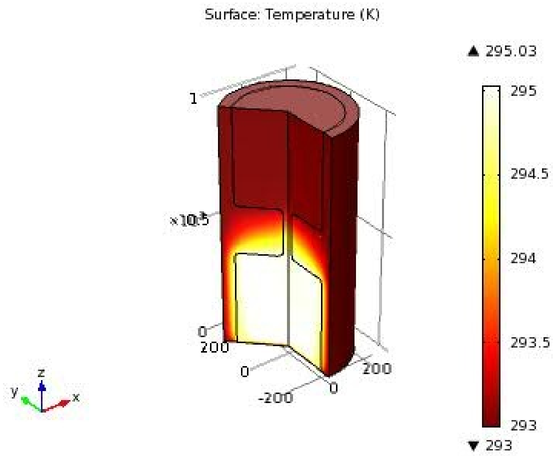

Figure 3: Figure showing the temperature rise in the constriction channel and throughout the outlet for high zeta potential value

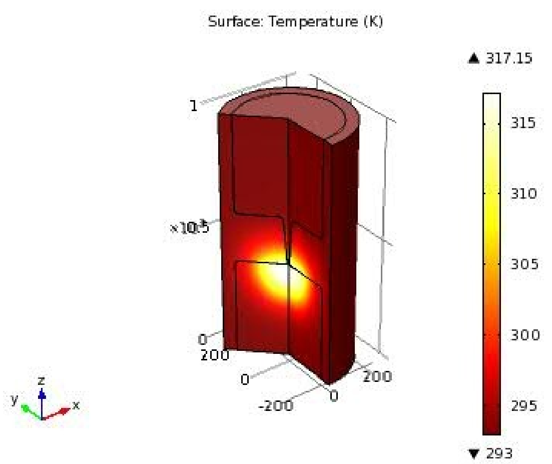

Figure 4: Figure showing the temperature rise at the end constriction channel due to tapering.